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Wind energy in Brazil—present and future

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Abstract

In Brazil, the power generation is predominantly hydroelectric, corresponding approximately to 91.4% of the installed capacity. The energy crisis in the Brazilian electric sector meant the end of the centralized generation and the launching of a decentralized generation approach aiming to add to the existing plants through small- and medium power capacity. Such a condition matches the wind energy characteristic profile. In northeastern Brazil is one of the most promising areas for wind exploitation, where the largest wind speed occurs exactly when the rate of flow in Sao Francisco river, which accounts for all the power energy supply of the northeast region, is low. Thus, during this critical period, the wind farms can produce electrical energy, saving the Sao Francisco waters and on top of that with no environmental risk, thus contributing to the overall reduction of CO_2 emission in the atmosphere. Because of those factors, the National Electrical Energy Agency (ANEEL), the Brazilian regulatory authority, has approved 77 projects for construction of wind farms, attracting foreign investment, besides the installation of wind turbine industries. The increasing use of the wind energy is prevailing over the absence of a specific legislation for the sector, but the National Congress has already taken some measures such as the act bill no. 2905/2000 and the temporary measure no. 14/2001.

Keywords: Wind energy; Regulation; Potential wind; Laws; Emission of CO_2

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Contents

1. Introduction

Hydroelectricity in Brazil accounts for about 91.4% of the installed power capacity. In the operating plan of the national electric system, coping with a high power demand in the dry season has been a historical challenge. The exploitation of a natural, clean and renewable resource—the wind energy conversion—can contribute to the self-sustainability of the Brazilian electrical system for the decades ahead.

The wind energy conversion has witnessed the highest growing rate in the last decade, taking the possibility of generating power by this technology to the scale of the giga watts. Its indubitable future is based on the following considerations: (a) Decentralized power production: geographically dispersed, wind power usually reinforces the grid ends, reduces power transmission losses, and increases the overall efficiency of the electrical system; (b) Costs: wind generation costs have maintained consistent annual decrease in a recent decades, and presently, the technology has reached generation cost levels that are already competitive with traditional technologies in many particular cases. The trend to full competitiveness is indicated by several factors including: the prediction of further cost reductions with the increase of industrial manufacturing scale, market expansion and a strongly competitive sector, and the technological evolution—new manufacturing processes, and bigger MW sized wind turbines. Furthermore, considering the increasing economic value assigned to environmental assets, and also as the negotiations regarding economical mechanisms to protect the climate evolve, wind energy poses no environmental risks,

especially when taking into account the usual 10–20 year payback of investment in power generation; (c) Generating jobs: in the wind technology case, the industrial activity of manufacture of wind turbine components prevails. Given adequate scale for wind farm expansion, a wide range of jobs are created, most of them requiring training and technical qualifications; (d) Technology settlement: large wind turbines demand a wide range of industrial activities, and some of them need human resources with multiple use, e.g. aeronautical techniques for light and stiff fiberglass structures, assembly, operation, development and maintenance of industrial level software and hardware, etc.; (e) Land leasing for wind farms: While wind farms harmoniously share land with the original farm and ranch activities, land lease payments have a very significant value in the rural economic environment [9]; (f) Laws: act bill no. 2905 and the temporary measure no. 14, replaced by law no. 10.438, assure a promising future for the wind energy.

This paper is organized as follows: Section 2 describes the structure of the Brazilian electric system; Section 3 deals with the Brazilian wind potential; in Section 4, the activities of the wind energy are presented; Section 5 runs through the contribution of the wind energy for the reduction of the emission of CO_2. In Sections 6–8, the legal, political and economic aspects are discussed, respectively, and finally the conclusions and the references are presented.

2. The Brazilian power sector structure

As in many parts of the world, the Brazilian electric power system has undergone a restructuring process which has as the main feature the de-verticalization of the sector activities into four segments: generation, transmission, distribution and commercialization. The market should become more competitive at two ends of the chain, i.e. at the production and commercialization segments. To run the restructured sector, three entities have been created: the National Electrical Energy Agency (ANEEL), the National Operator System (ONS), and the Wholesale Market of Energy (MAE). ANEEL is in charge of carrying out the regulation and control of the sector; ONS coordinates, plans, and operates the electric interconnected system; and MAE runs the energy wholesale market.

At present, the principal Brazilian electric power generation and transmission segments are state owned. Although the system is classified as hydrothermal with an overall installed capacity of about 79 GW, there is a strong predominance of hydroelectric plants distributed in 12 different hydrographic basins located in different areas of the country. Except the nuclear plants, these are supplemented by thermal, nuclear and wind plants with several public and private owners.

In Fig. 1, the electro-energy integration can be seen between the production system and the load centers interconnected by the transmission system. Through the transmission line system, which works as communication links, it has been possible to accomplish the transfer of energy among regions for the recovery of the reservoir storage levels, which are located, apart from the extreme northern, in the southern parts of the country.



Fig. 1. Brazilian hydrogeneration interconnected by transmission lines and the load centers.

In spite of the new model recently established in Brazil, there are still federal and state owned electric companies that were targeted for privatization, but due to the 2001 energy shortage crisis in the electric sector, privatization has been halted.

According to the ONS, at the end of 2001, the country's installed power capacity was 67.987 MW, distributed among different generation types as displayed in Table 1 [6], which shows 80% of the capacity based on hydroelectricity.

Table 1
Capacity installed at plants (source: ONS [6])

Types of plants	Installed power (MW)
Hydroelectric	54,694
Thermal	5,027
Nuclear	1,966
Itaipu (50%)	6,300
Total	67,987

The energy crisis in 2001 brought about by political and economic issues and aggravated by a long dry season resulted, as a consequence, in the decision of mixing various other energy resources for electricity generation. Programs like PROINFA that supports renewable energy projects comprising wind, biomass, solar and small hydroelectric plants, and PPT/PET programs related to thermoelectric plants are examples of policies taken by ANEEL in order to overcome the energy crisis.

Among the renewable resources, wind energy has emerged as the most promising alternative due to the suitable wind conditions along the country's northeast coastline (3347 km) including the states of Ceará, Rio Grande do Norte, Pernambuco and Bahia with some plants already in operation.

3. Wind energy in Brazil

Humanity has learned how to take advantage of the wind energy to perform various activities along time. The most traditional way of exploiting includes the wind mills used for grinding, agriculture, irrigation and water pumping. Another important use even today is for sailing based on candles. More recently, wind energy has been used for electricity generation, and since then, Brazil has realized its great wind energy potential.

The recently published wind map [16] has reaffirmed the great potential that is yet to be exploited in the country.

In Brazil as well as in many parts of the world, quality wind data hardly existed for an accurate evaluation of the wind potential. The first computerized anemograph and sensor specially for wind energy were installed in Ceará and in the archipelago of Fernando of Noronha in Pernambuco, in the beginning of the 1990s. The good results from the first data acquisition favored a more accurate plan of measurement ending up with the installation of wind turbines in those places.

After that, other Brazilian states followed the steps of Ceará and Pernambuco and set programs for wind data acquisition. Now, there are more than a 100 computerized anemographs located among several Brazilian states.

As aforementioned, one of the most promising and favorable areas for wind energy conversion is the northeast region. It is noteworthy that the Sao Francisco River is the most important resource of electricity generation to the northeast of Brazil, and the largest wind speeds occur exactly when the flow of water of Sao Francisco River is at a low level, as shown in Fig. 2. Therefore, besides suitable wind energy conversion conditions like speed, frequency distribution, degree of turbulence and gustiness, the wind plants installed in the northeast can produce electric power saving the Sao Francisco waters.

The analysis of the wind data of several places in the northeast has confirmed the calling for wind trading existing in the area: high average wind speeds ($>$8.5 m/s), low turbulence level at the whole year with Weibull factor k larger than 3—values considered very high (indicative of low turbulence) when compared with the winds registered in Europe and United States, and an indication of steady wind direction.

A preliminary wind map of Brazil from The Brazilian Center of Wind Energy

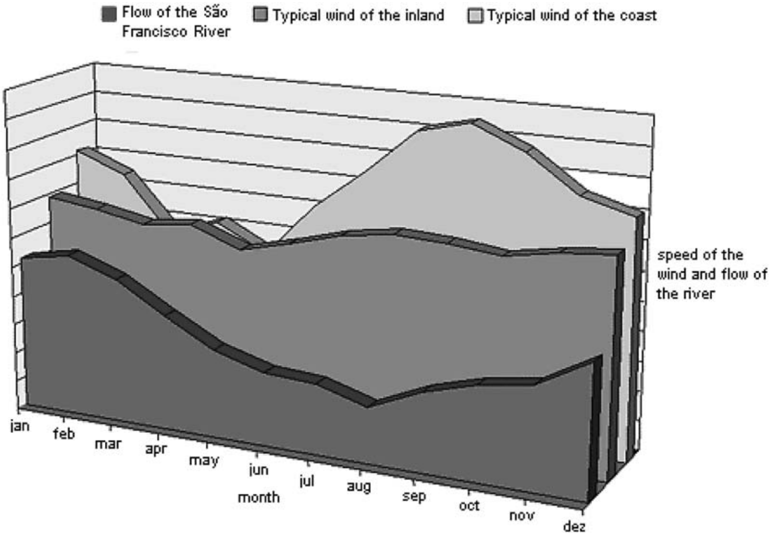


Fig. 2. Comparison between the river flows of Sao Francisco and the wind regime in the northeast of Brazil.

(CBEE) using computer simulations and based on atmospheric models is shown in Fig. 3. It can be observed that the best wind speeds are in the coastal areas not discarding the possibility of good winds in the inland.

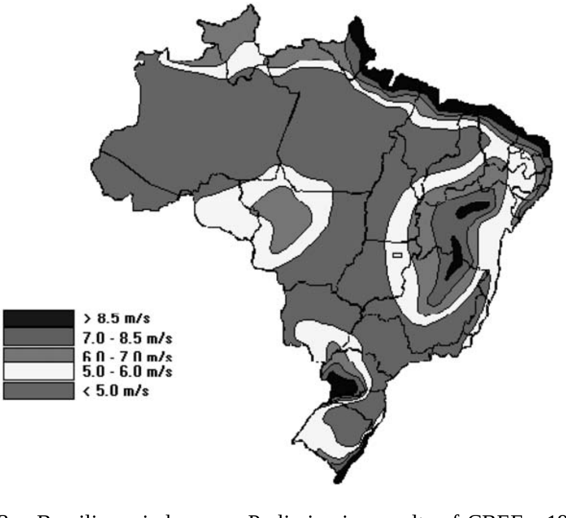


Fig. 3. Brazilian winds map—Preliminaries results of CBEE—1998.

4. Activities of the wind energy

Brazil began the new century with a serious and undesirable electrical energy crisis. The crisis brought along with it a new paradigm and various new programs for the electric sector. The feasibility of any project ought to be focused on the warranty of safe provisions of electric power.

Particularly in the northeast, the energy crisis meant the end of the centralized electricity generation, materialized through eight hydroelectric plants along the river Sao Francisco adding together 9872 MW of installed capacity. The required paradigm is based on a decentralized generation approach through the initiative of new facilities of small- and medium load capability, being the characteristic profile of the wind energy.

To accomplish the new paradigm, ANEEL has launched the Wind Energy Emergency Program (Proeólica) through Resolution No. 024 of July 5th, 2001, with the purpose of reaching a wind generation capacity of 1050 MW before December 2003, 50 times greater than the current wind power installed capacity. The enterprises would have an energy purchase contract guaranteed by Eletrobrás, for 15 years, and incentives on the energy price with an increase of 20% above the normative value for plants installed before December 31, 2001, reducing to 10% above the normative value for plants installed before December 31, 2002 [7].

The northeastern states of Rio Grande do Norte, Ceará, Piauí, Bahia, Sergipe and Pernambuco would have, before 2006, 61 out of the 77 approved projects, the state of Rio de Janeiro the other two, in the state of Rio Grande do Sul the other 13 and in the state of Santa Catarina the other one, as shown in Table 2.

Besides the projects already approved, there are many other registration requests to be appraised by ANEEL.

At present, the installed capacity in Brazil of electric–wind conversion is 21.42 MW, with wind turbines of medium sizes connected to the electric network.

Table 2
Wind farm projects approved by ANEEL (source: ANEEL [5])

States	Year of commencement of operation			
	2003 (MW)	2004 (MW)	2005 (MW)	2006 (MW)
Rio Grande do Norte	1,279.25	537.85	119.85	29.70
Ceará	1,070.05	732.10	231.20	–
Bahia	119.00	49.73	80.33	–
Pernambuco	69.40	208.40	89.10	–
Piauí	–	–	–	23.40
Sergipe	17.10	–	–	–
Rio de Janeiro	174.60	–	–	40.00
Rio Grande do Sul	–	635.55	231.00	113.00
Santa Catarina	9.00	–	–	–
Total	2,738.4	2,163.63	751.48	206.10
Total grand	5,859.61 MW			

In Ceará, there are three wind farms: Mucuripe (2.4 MW), Taíba (5 MW) and Prainha (10 MW); in Pernambuco, the wind farms are in the archipelago of Fernando de Noronha (0.3 MW) and Olinda (0.225 MW); in Paraná, the wind farms are in Palmas (2.5 MW), Bom Jardim (0.6 MW), and in Minas Gerais, the experimental wind farm is in Morro do Camelinho (1.0 MW). Dozens of other small and dispersed wind turbines are in operation usually as isolated systems for several applications, such as pumping, shipment of batteries, telecommunications and rural electrification.

The growing market of wind energy conversion in Brazil has led to the establishment of wind turbine factories, Wobben Wind Power, a subsidiary of the German Enercon, in Sorocaba—SP and recently a unit in Ceará. The industrial unit in Ceará has started to produce shovels (rotors) for the wind turbines, but from 2004, it will supply the entire wind machine. The factory in Ceará will have the capacity to manufacture up to 300 wind turbines a year of 0.6 MW each and will export primarily to Europe, but it will also address the South America and Brazil market.

In Brazil, the wind plants are operated by private investors and most of them are in the northeast region for its favorable wind conditions. Among the authorized investors to exploit electric–wind conversion are Enerbrasil, from the Spanish group Iberdrola, Electricité of France (EDF), the German Fhurlander and CL Participações, a Brazilian group—without taking into account Wobben Company that operates the three parks in Ceará, totaling 17.4 MW, representing 75% of the wind energy conversion plants in the country [8].

5. Contribution for the reduction of the emission of CO_2

Companies such as Citroen Peugeot, American Company Central and Southwest Corporation—CSW, General Motors and Texaco have been investing million of dollars in Brazil in reforestation programs for CO_2 absorption. According to specialists in renewable energy, that money could be invested successfully in the reduction of global warming through measures such as wind and solar energy conversion. Instead of the estimated US $50 million to be used in carbon sink projects in Brazil as announced by these companies, it would be better to instal 50 MW of wind turbines.

Based on the data of the wind map of the states of Paraná and Ceará, developed by the electric power companies, for wind speeds around 7 m/s in the state of Paraná, the wind farms would need 25 km^2 area and would generate 120 GWh of electricity per year. This generation of energy would avoid at least 43,000 tons of CO_2 emissions per year. In the state of Ceará, for the same range of speed, the wind farms would generate 51.9 TWh of electricity per year and would avoid around 46,000 tons of CO_2 emissions per year.

Since Brazil has remarkable wind conditions, non-government organizations (NGOs) in Brazil, for example, Greenpeace and another 23 Latin America environmental organizations, signed a document against carbon sink projects and set up a campaign to increase investments in renewable energy [15].

6. Legal aspects

One of the main obstacles for the development and operation of wind plants in Brazil is related to the regulation issues of wind energy, although the National Congress is making lots of effort to overcome the barriers. In 2000, it has created the act bill 2905/2000, in 2001, the temporary measure no. 14, of December 21, 2001 [1], and in July 2001 the Resolution No. 024, as previously mentioned. A decisive step was the promulgation of law no. 10.438, of April 26, 2002, which incorporated the temporary measure no. 14, creating the Electric Energy Renewable Sources Incentive Program (PROINFA), the Bill of Energy Development (CDE), and it disposes of the universalization of the public service of electric power.

6.1. Act bill no. 2905, 2000

The act bill no. 2905, 2000 [2] amends law no. 5655 of May 20, 1971, no. 5899, of July 5, 1973, no. 9074, of July 7, 1995, no. 9427, of December 26, 1996, no. 9648, of May 27, 1998 and it gives other provisions. On the other hand, law 9648 of May 27, 1998, besides authorizing to alter and to complement other legal devices, also empowers the executive power to promote the restructuring of the Brazilian Electric Headquarters—ELETROBRÁS and its subsidiaries, and it gives other provisions. Amongst the provisions, it is the development of the free electric power market, where buying and selling energy become market driven; however, there will be a transition period between 1998 and 2005. Starting from 2003, the volumes of energy initially contracted will be reduced gradually, 25% a year, and liberated for use in the market.

Law 2905 of 2000 establishes that the electric power generation from renewable sources should be contracted for a period of not less than 10 years, till it reaches 10% of the supply markets, estimated in 20 years as a result of the ANEEL regulation procedures. The renewable power that can be undertaken will be carried out by an annual purchase program to provide a minimum of 20% of the annual increment of the energy to be supplied to the final customer by the utility or dealer agent. This acquisition should be accomplished considering the reference value of electric power generation (VR), assumed as a medium cost of generation of new enterprises of hydraulic generation with superior power 30.000 kW, to be published by ANEEL.

The established values of reference for renewable energy based generation (VA), revised every 5 years by ANEEL [2], are:

I—wind: 1,75 X VR
II—solar: 4,15 X VR
III—biomass: 1,40 X VR
IV—small central hydroelectric: 1,25 X VR

6.2. Law no. 10438 of April 26, 2002

Law no. 10.438 of April 26, 2002 [3], besides other aspects, has incorporated temporary measure no. 14, of December 21, 2001. This law ratifies the creation of

the Electric Energy Renewable Sources Incentive Program—PROINFA, that aims to increase the participation of electric power generation by independent producers based on wind, solar, and biomass resources and small hydroelectric plants interconnected to the network system.

To ensure successful development for the renewable energy program, PROINFA was divided into two stages: the first one tries to encourage the production of 3300 MW till December 30, 2006, with the generated energy purchase assured by ELETROBRÁS in a period of 15 years. The installed capacity will be divided equally by each one of the participant sources of the program and the acquisition of the energy will be made by the corresponding economic value of the specific technology of each source. The economic value will be defined by the executive power, based upon 8% of the national average tariff applied to the end user.

The submitted projects to the ANEEL approval must meet environmental standards and requires an environmental license. An important aspect for attracting the wind industry development is the opportunity of wind related equipment manufacturers to participate as an independent producer on their own or in cooperation, since the equipment rate of nationalization is, at least, 50%.

The second stage of the program can be defined as criteria to move on the renewable energy program, since it enforces the participation of renewable energy resources in the framework of energy of Brazil. For such instances, the renewable resources should add up 10% of the country's annual demand of electric power, a target to be reached within 20 years, where 3300 MW from the first stage are included.

Contracts and prices will be those previously defined in the first stage, and the acquisition will be made according to the annual agenda of purchase of electric power from each producer, so that they must deliver a minimum of 15% of the annual increment of electric power to be supplied to the national market, compensating in the subsequent period the deviations observed between the forecasted and the implemented values of each period. Furthermore, the producer of renewable energy will deserve a complimentary credit to be paid monthly with resources of the Bill of Energy Development—CDE. This value, which is defined by the executive power, should be at least 80% of the national average tariff charged from the end consumer, and is based on the difference among the economic values corresponding to the specific technology of each source and the value received from ELETROBRÁS.

The Bill of Energy Development—CDE has the objective of promoting the energy potential of the states and the competitiveness of the energy produced beginning from wind sources, small hydroelectric plants, biomass, natural gas and national mineral coal, in areas assisted by the interconnected systems and in promoting access to electric power service all over the country.

The control of the types of renewable resources and production amount will be evaluated through annual reports produced until January 30 of each exercise. For the report, the producers will produce a certificate of renewable energy—CER, which consists of, at least, the producer agent's juridical qualification, the type of the primary renewable resource used and the amount of electric power marketed in the

previous exercise, to be presented to ANEEL for fiscalization and control of the annual goals.

This law stimulates a balanced participation of the different types of producers of energy taking part in the program by limiting the transfer of annual resources, so that the total value cannot exceed 30% of the CDE's annual budget. Furthermore, the acceptance of projects and contracts is subjected to a previous verification, by ELETROBRÁS, of the availability of the economic resources. However, this law establishes that in the case of absence of development of any one of the types of energy involved, it is possible to revise the goals every 5 years of implementation of this second phase, transferring the surplus of generation capacity of any one type to other types of energy.

A business enterprise based on renewable resources that begins commercial operation at the end of 2006 can request CDE support for the first 5 years of operation, through credit, since there is no cumulative benefit where PROINFA and PPT programs are concerned. CDE will prevail for 25 years, and will be regulated by the government executive sector and by ELETROBRÁS.

7. Political aspects

The energy crisis that occurred recently in Brazil had two basic causes, the lack of investments in the electric sector, and the great dependence of electric power on hydroelectricity. The crisis has brought up the need of the significant measures to be taken. One of the major measures defended by the Camera of Administration of the Energy Crisis is "to promote a significant alteration of the energy framework with a larger participation of gas thermal plants and renewable energy sources". These measures demand amendments in the environmental legislation and in the licensing process and the regulation of new plants and sources of energy [10].

In spite of the National Institute of Space Researches' (INPE) assurance that another crisis is unlikely since the reservoirs have a good water level because of the drop in electricity demand [11], thereby resulting in surplus energy [12], the next government will have a significant challenge in equating the supply problem and the source of energy. The initiative to promote gas thermoelectric plants as an alternative to the energy crisis faces a dilemma as the gas is imported and the price is bound to the American dollar, and on top of that the generated electricity competes with electricity from hydroelectric plants. These uncertainties have drawn back investors and have delayed the projects [13].

Therefore, investment in renewable sources such as wind based power plants is desirable and strategic to diversify the national energy balance, which present competitive costs and adequacy to the Brazilian reality.

8. Economic aspects

The cost of wind based energy in Brazil is still about 70% above that of the hydro-based counterpart (see values of reference). However, the price of wind based electric

energy tends to reduce. On the other hand, the costs of the hydroelectric energy tend to increase, especially in environmental terms due to the flooding of extensive forest or agricultural areas, necessary for reservoirs. The transmission system adds to the cost of the energy because the plants are usually far away from the load centers. Another advantage of wind farms as regards the hydroelectric plants is that almost the whole area of the wind farm can be used for agriculture, livestock purposes, etc. or preserved as a natural habitat.

Among the renewable and environmental friendly energy sources, wind is one of the cheaper ones. While the MW price of the solar based energy is $72.0, that of wind based energy is $34.0, which is higher than the hydro-based energy which costs $22.0/MW.

Considering the great wind potential in Brazil, it is possible to produce electricity at competitive costs together with thermo-electrical, nuclear and hydroelectric conversion. The analysis of the wind resources measured in several places of Brazil shows the possibility of electric generation with costs in the range of US$ 70.0 to US$ 80.0 per MWh.

9. Conclusion

Wind energy has a commercial and well-balanced technology, which has been used in a wide scale in developed nations since the beginning of the 1990s, usually with government subsidies.

In the west coast of the USA (mainly in the mountains of the state of California), and in Europe, especially in the north of Germany and Denmark (the coast of the North Sea), wind energy is already a complementary source to the conventional electric generation, responsible for 3.82% of production in Germany [14]; in Denmark, the production reaches 12% [4]. In Brazil, the installed wind power corresponds to about 2.7% of the generated capacity [4].

Considering the number of projects approved and in construction in the period from 1998 to 2000, the capacity of Brazilian generation would go to 119,361,602 kW, which would increase the wind participation to 4.15% of the total installed capacity, contributing to CO_2 emission reduction of the same amount.

When the wind energy program is completely implemented, Brazil will become one of the five largest producers of wind energy in the world.

The investment of the Brazilian electric sector and the signaling of incentive policies for alternatives energy sources make the future of wind energy in Brazil very promising and true.

References

[1] Temporary measure no. 14, December 21, 2001.
[2] Act bill no. 2905, 2000.
[3] Law no. 10.438, April 26, 2002.

[4] The Brazilian Center of Wind Energy (CBEE). Available from: http://www.eolica.com.br.
[5] National Electrical Energy Agency (ANEEL). Available from: http://www.aneel.gov.br.
[6] National Operator of the Electric System (ONS). Available from: http://www.ons.org.br.
[7] Electric Central Brazilian S.A., ELETROBRÁS. Available from: http://www.eletrobras.gov.br.
[8] Moreira D. Investments inflated in wind energy. In: C&T in the media. Ministry of Science and Technology.
[9] SEINFRACE. Secretary of infrastructure—government of state of Ceara: wind energy resource atlas of state of Ceara, Brazil, 2001.
[10] Goldemberg J. Energy in the United States and in Brazil. The state of Sao Paulo. May 29, 2001. Available from: http://www.estado.estadao.com.br/editorias/01/05/29/aberto002.html?ap.
[11] News of the Electric. INPE discards rationing of energy. Available from: http://www.eletrica.com.br/noticias/noticias.asp? Id—Noticias=14113.
[12] News of the Electric. Offer excess threatens auction of energy for 2003. Available from: http://www.eletrica.com.br/noticias/noticias.asp?Id—Noticias=14110.
[13] News of the Electric. Iberdrola plans construction of wind farm in Bahia. Available from: http://www.eletrica.com.br/noticias/noticias.asp?Id—Noticias=14118.
[14] German Wind Energy Institute. DEWI. Available from: http://www.dewi.de/statistics.html.
[15] Casagrande Jr EF, Schultz DJ. CO2 emissions trade in Brazil: a choice between CO2 ionization and wind energy generation.
[16] CRESESB. Atlas do Potencial Eólico Brasileiro, 2002.